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Carlo Castagnoli, Pio Picchi, Giuseppe Verri

On the arrival time distribution of the muonic and hadronic component in EAS

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Fisica. — *On the arrival time distribution of the muonic and hadronic component in EAS* (*). Nota di CARLO CASTAGNOLI, PIO PICCHI e GIUSEPPE VERRI, presentata (**) dal Socio G. WATAGHIN.

RIASSUNTO. — I dati sperimentali sui ritardi di muoni misurati sotto roccia a 70 m.a.e. sono confrontati con quelli calcolati con un Monte Carlo. Il modello della cascata nucleonica scelto è quello isobarico. Si ottengono risultati in buon accordo con l'esperienza. I ritardi sulla componente adronica mostrano invece un certo disaccordo con gli scarsi risultati sperimentali oggi noti.

The interest of a study on the arrival time distribution of the muonic and hadronic (nuclear active) component of EAS has been spurred by two facts: 1) the experimental investigation of such components has already given some partial insight into their temporal analysis [1]; 2) some methods for the search of quarks or plutons rest on measurements of the arrival times of EAS heavy particles both underground [2, 3] and at sea level [4] whose background is of course constituted by the tail of the muon and n.a. particle temporal distribution.

We studied this arrival time distribution with a Montecarlo method to overcome the very complex problems a detailed study of the nuclear cascade would have to face. Several authors [5, 6] have carried out calculations on the nuclear cascade in EAS but not on the temporal distributions.

The nuclear cascade model we developed in a previous work [7] rests on the following points: 1) it is a composite isobaric model; 2) the evaporation of the fireball produces 80 % of mesons; 3) the isobars taken into consideration have masses 1410 and 1638 MeV; 4) the collision inelasticity is 0.4 and varies little with the primary energy; 5) the angular distribution of secondaries in the Laboratory system is Gaussian in 60 % of the cases and alternatively double peaked; 6) the transverse momentum distribution is of Boltzmann type.

This model has given results in good agreement with the experimental lateral and energy distribution of the EAS muonic component as well as with the behaviour of the nuclear active (n.a.) particles in the cascade.

Fig. 1 shows the agreement between the computed energy integral spectrum of the n.a. particles and the experimental results of Tanahashi [8] for EAS of size $N = 5 \cdot 10^3$ particles. Fig. 2 shows the results on the total energy carried by the nuclear active particles: the value we computed is in agreement with the value obtained by the experimental data. We thus retain our cascade model satisfactory also for the nuclear component and go on discussing the temporal properties of the cascade.

(*) Laboratorio di Cosmo-geofisica del CNR e Istituto di Fisica Generale dell'Università, Torino; Laboratori Nazionali del CNEN, Frascati.

(**) Nella seduta dell'11 gennaio 1969.

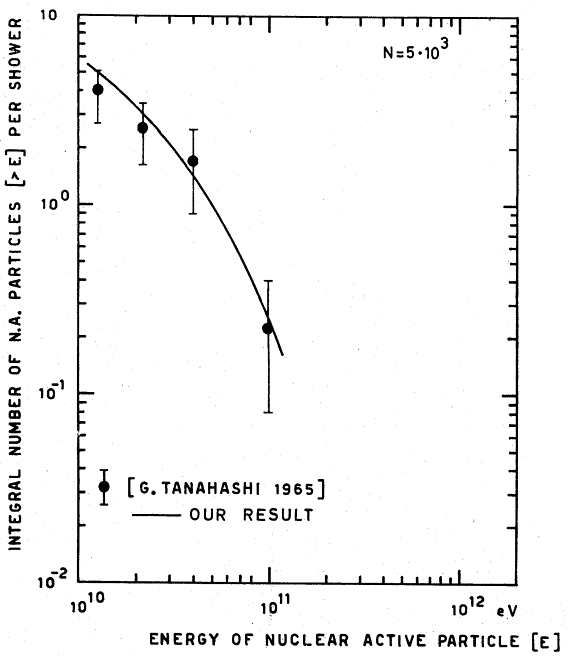

Fig. 1. – Integral number of hadronic (n.a.) particles in EAS of size $N = 5 \cdot 10^3$.

The experimental points are due to Tanahashi (1965).
The curve represents our calculation.

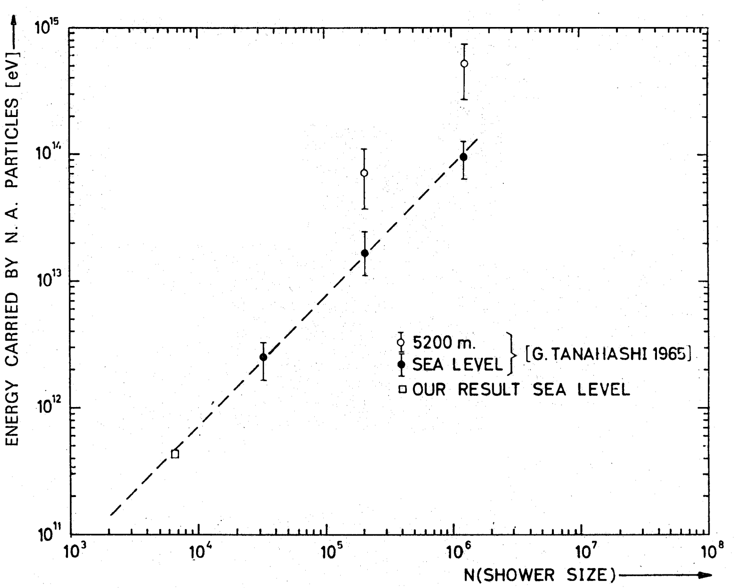

Fig. 2. – Dependence of the energy carried by the hadronic component on the total number N of particles in the shower.

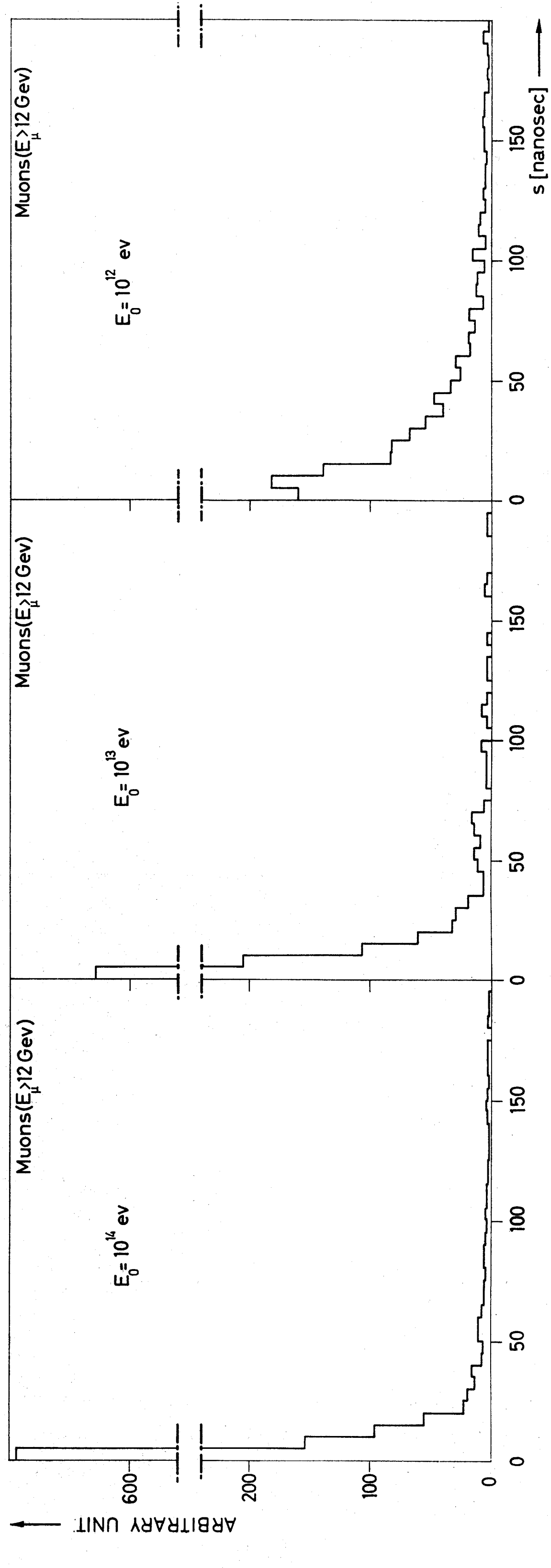

Fig. 3. – The arrival time distributions of energetic muons in EAS of $E_0 = 10^{14}$, 10^{13}, 10^{12} ev.

Fig. 3 gives the delays up to ~ 200 ns of muons in the shower with respect to the first EAS muon which arrives at the depth of 70 m.w.e. (that is $E_\mu > 12$ GeV). It may be seen that the delays show the expected strong dependence on the primary energy E_0.

This result is to be compared with the experimental data of the Turin group obtained by measuring the delays between the μ pairs which hit a 5 scintillator telescope device situated underrock at 70 m.w.e. Fig. 4 shows such a comparison, obtained by inserting the results of fig. 3 in a simple Montecarlo calculation and taking into account the device geometry and the primaries spectrum. The agreement is very satisfactory.

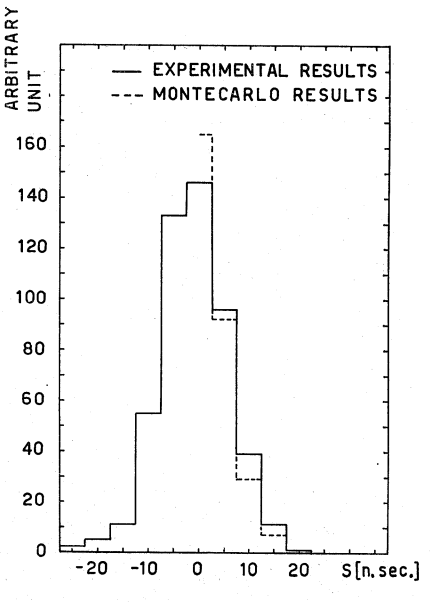

Fig. 4. – Comparison of the delays between two muons observed at 70 m.a.e. and calculated according to our model.

The arrival time distribution (with respect to the first hadronic particle of the EAS) of the pions and nucleons with energy > 12 GeV, and of their sum, i.e. of all the nuclear active particles is reported in fig. 5, compared with the experimental data of Chatterjee *et al.* [1] who is the only one to have studied the time lags of hadronic particles in EAS, at a height of 2200 m. above s.l.

His work shows that the time lags of the hadronic particles of energy ≥ 7 GeV extend up to 250 nsec in agreement with our model. Our distribution is however more sharply peaked than the experimental one. This confirms the assertion of the authors [1], namely that if the hadronic particles recorded were predominantely pions then such a broad experimental distribution cannot be understood (our calculation assumes $\sim 80\%$ of pions against 20% of nucleons). It is of interest to investigate experimentally this point with

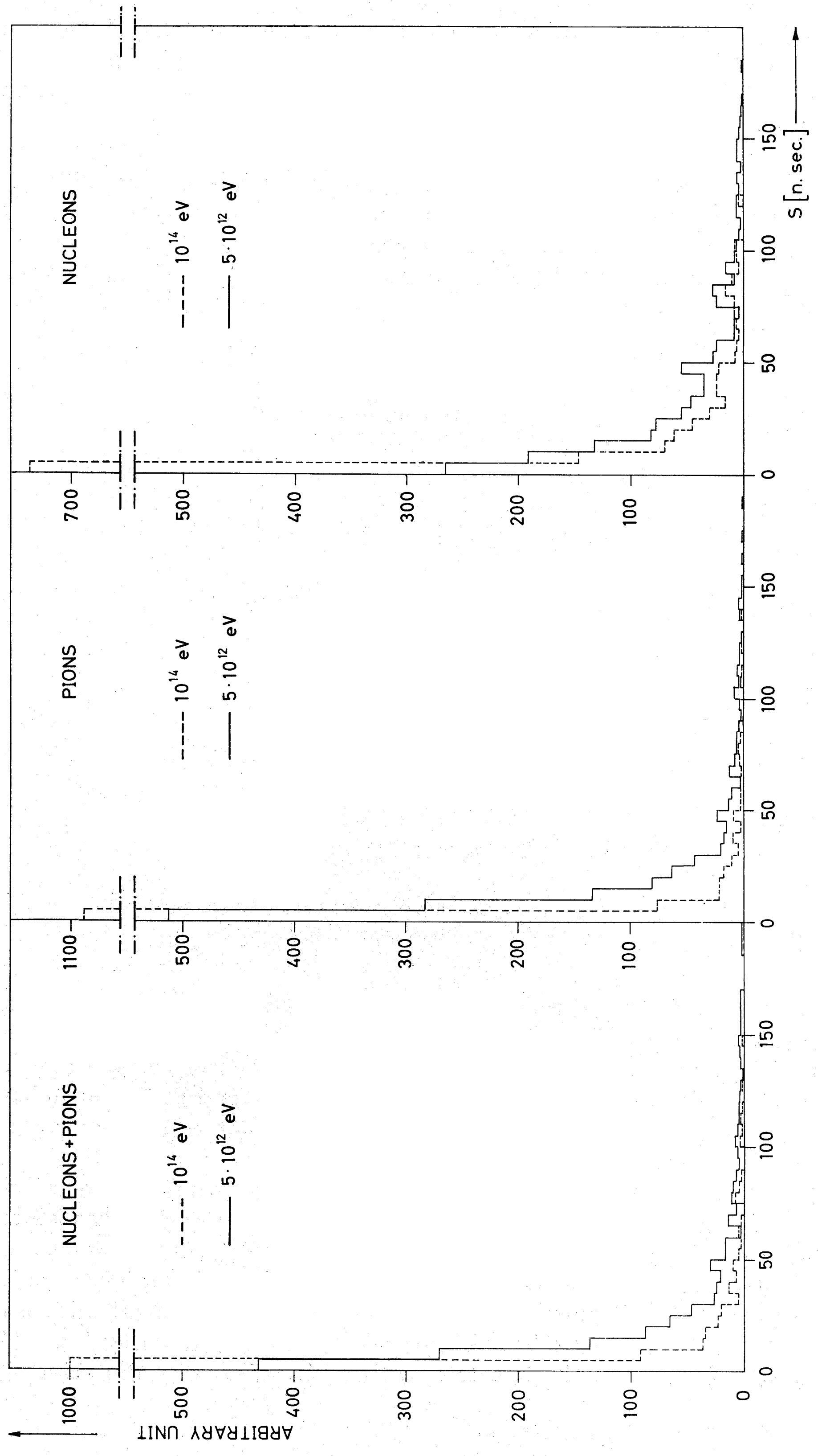

Fig. 5. – The arrival time distributions of energetic nucleons and pions in EAS of $E_0 = 10^{14}$ ev and $5 \cdot 10^{12}$ ev.

other devices and other experimental conditions in order to prevent any instrumental bias. As a conclusion we observe that the tails of the two distributions are remarkable.

The rarity of pluton events makes us understand the importance of this background in sea level EAS. The measurement of delayed particles does not seem to be by itself a sufficient experimental method for the identification of a heavy component in the cosmic radiation. The time lag measurements will have to be accompanied by measurements on other parameters such as for instance the charge (as our group is now doing in an experiment at Testa Grigia) or the interaction mean free path (as done by Dardo *et al.* [3]).

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